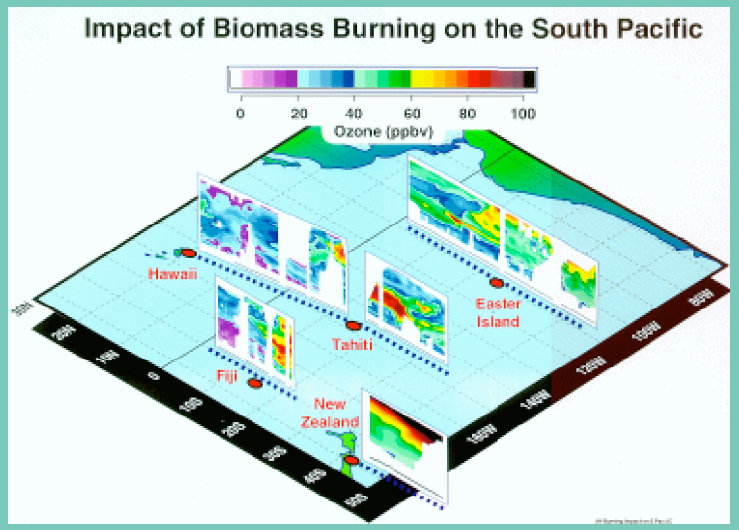
A Central Role for South and Central Africa in Global Pollutant Transport



Robert Chatfield

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(Ames Res. Ctr, California, USA)

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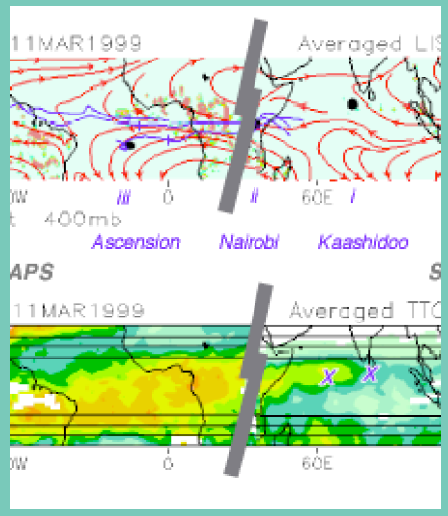

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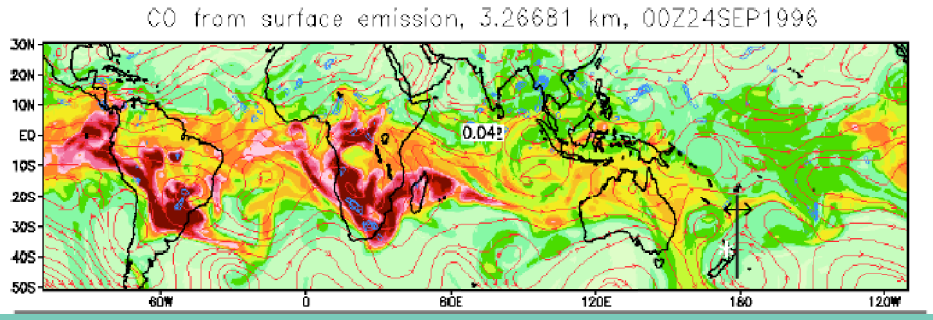
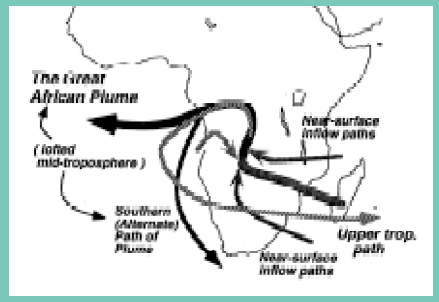
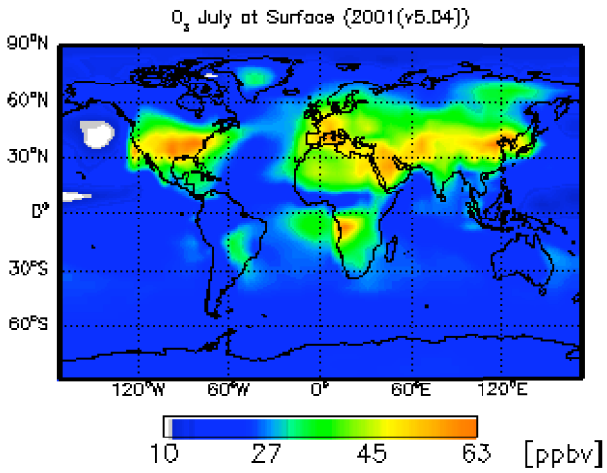




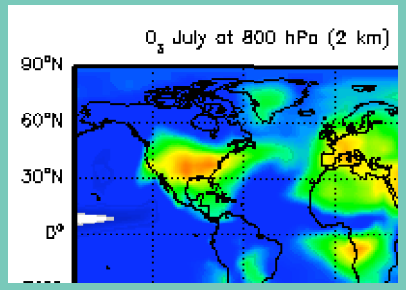
Early Concepts of Continental Plumes

Original ideas of pollution plumes:



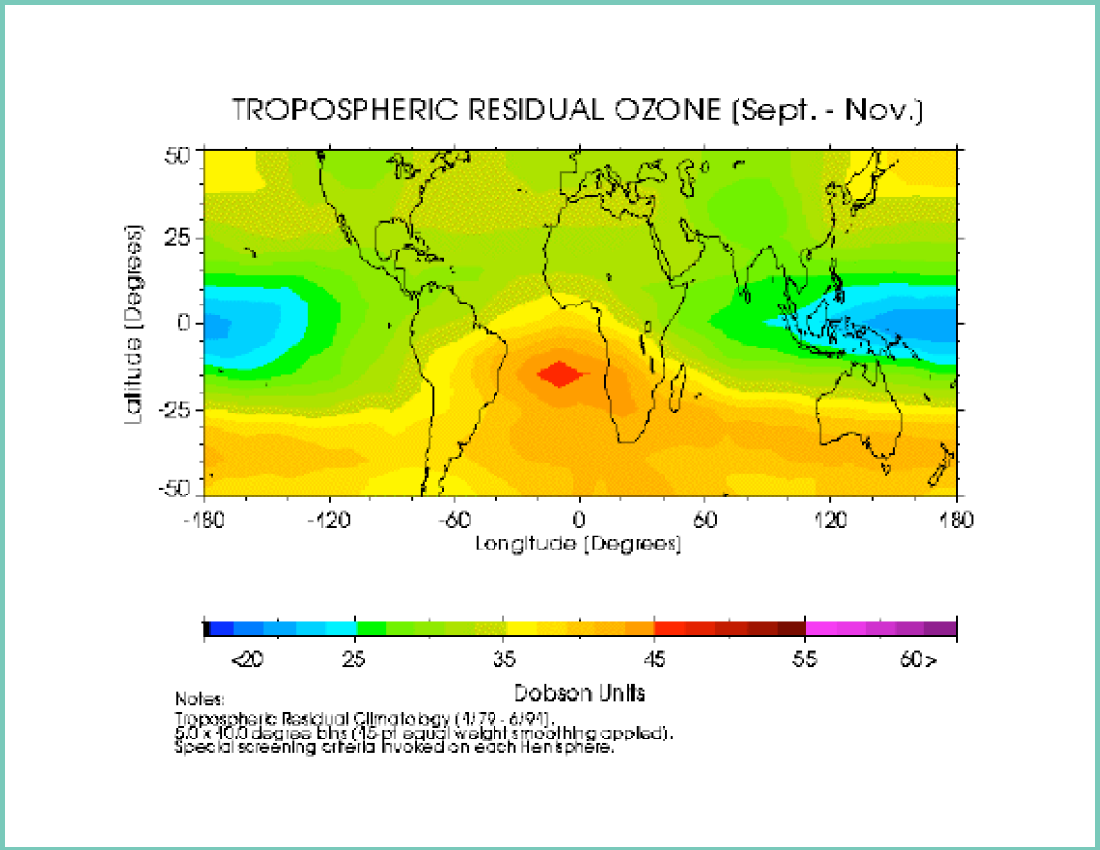
Harvard U.: GEOS-CHEM website

Continental plumes were extensions of urban plumes, which might merge and move out westward in the PBL.
Mostly Northern Industrial-Urban
Theory was an extension of industrial, urban



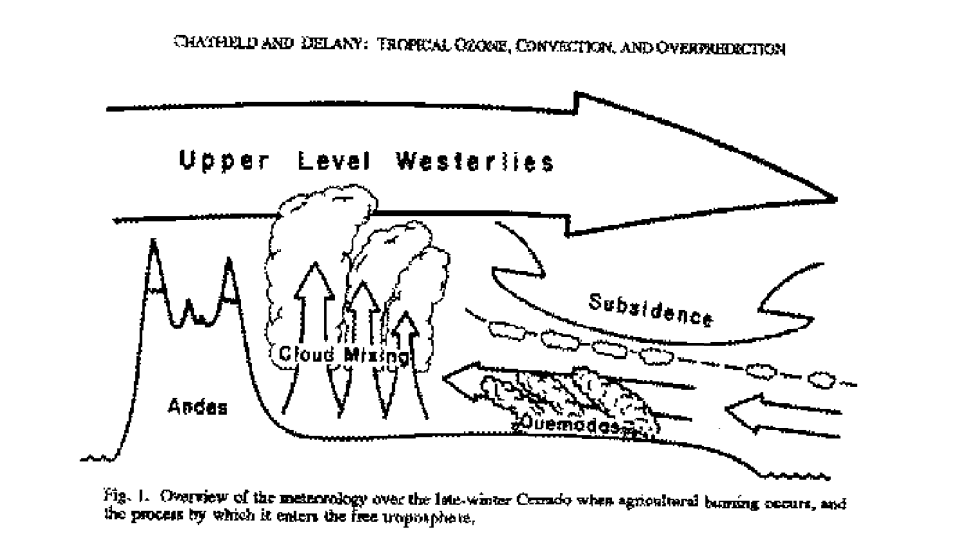
Fishman and Vukovich noted plumes could move forward by filling a deep continental PBL and then "override" a thin marine PBL, gaining velocity and isolated from some destruction.
(An early use of TOMS data for tropospheric interpretation.)

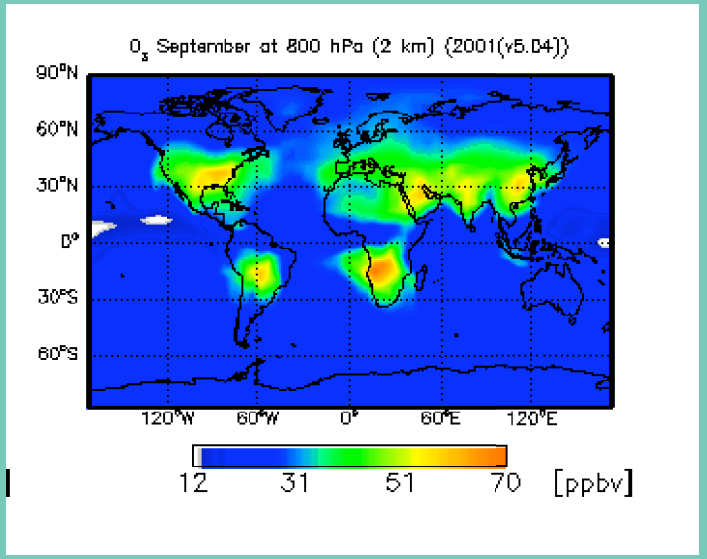
"Jack's Max"



When Jack Fishman applied an early technique of subtracting stratospheric ozone,
... northern plumes were visible but the unexpected story was a prominent near-Equatorial ozone maximum, "Jack's Max"

Similarly, early CO sampling from the MAPS instrument on the Space Shuttle indicated buildups and plumes in the southern subtropics in October





Chatfield and Delany, 1990

New theory was required to explain this: even current models at 4x5 degree resolution have difficulties.

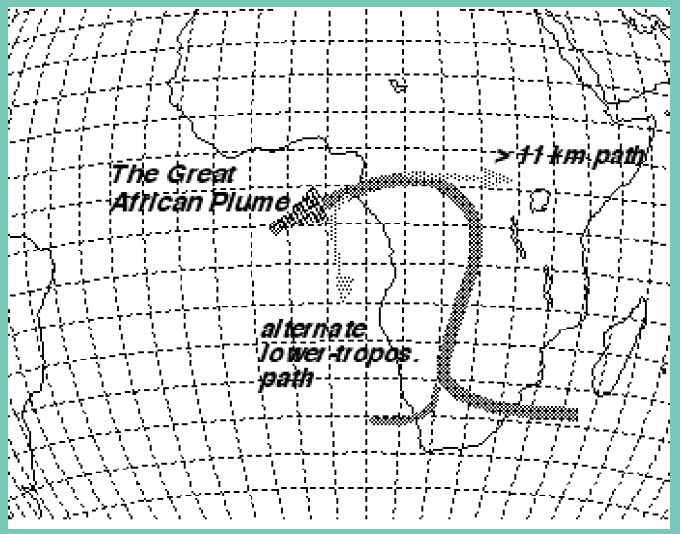
Various explanations including stratospheric ozone came forth

I first favored an explanation involving lofted pollution

1) South America, cloud venting

... then

2) Africa, with cloud and PBL venting



Chatfield et al, 1996

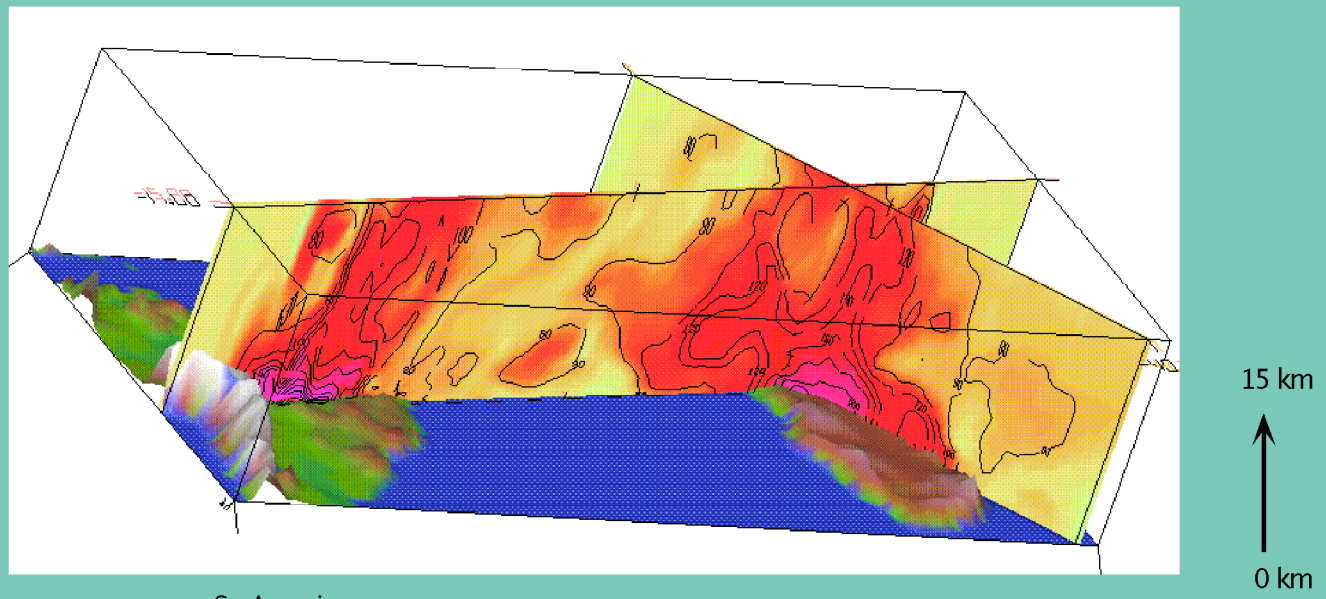


Figure 2

Chatfield et al., 1996
NASA program 579-24-13-10

Make an idealized model of this flow in detail

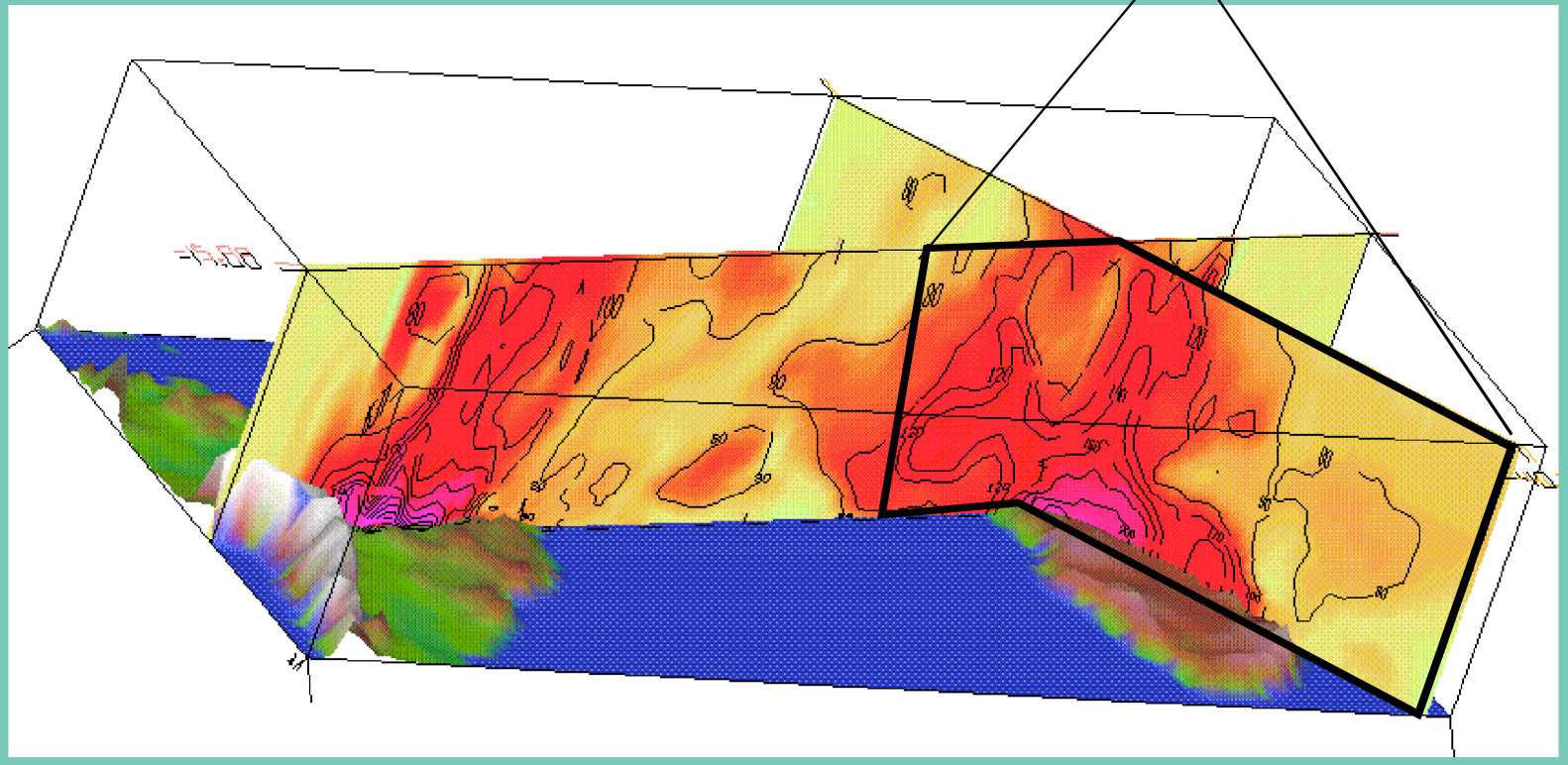
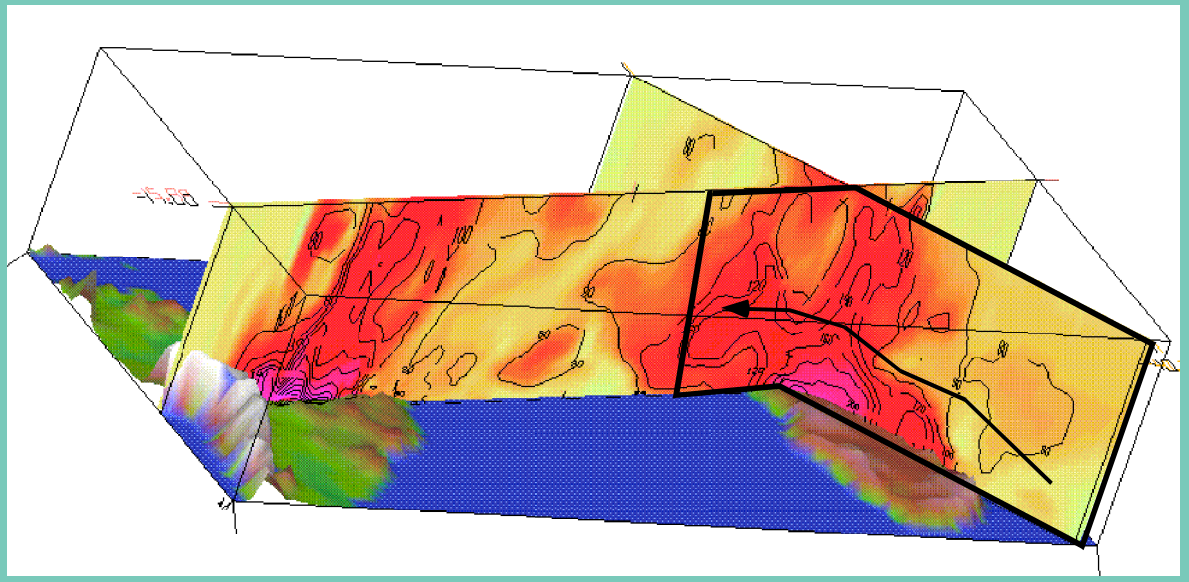


Figure 2

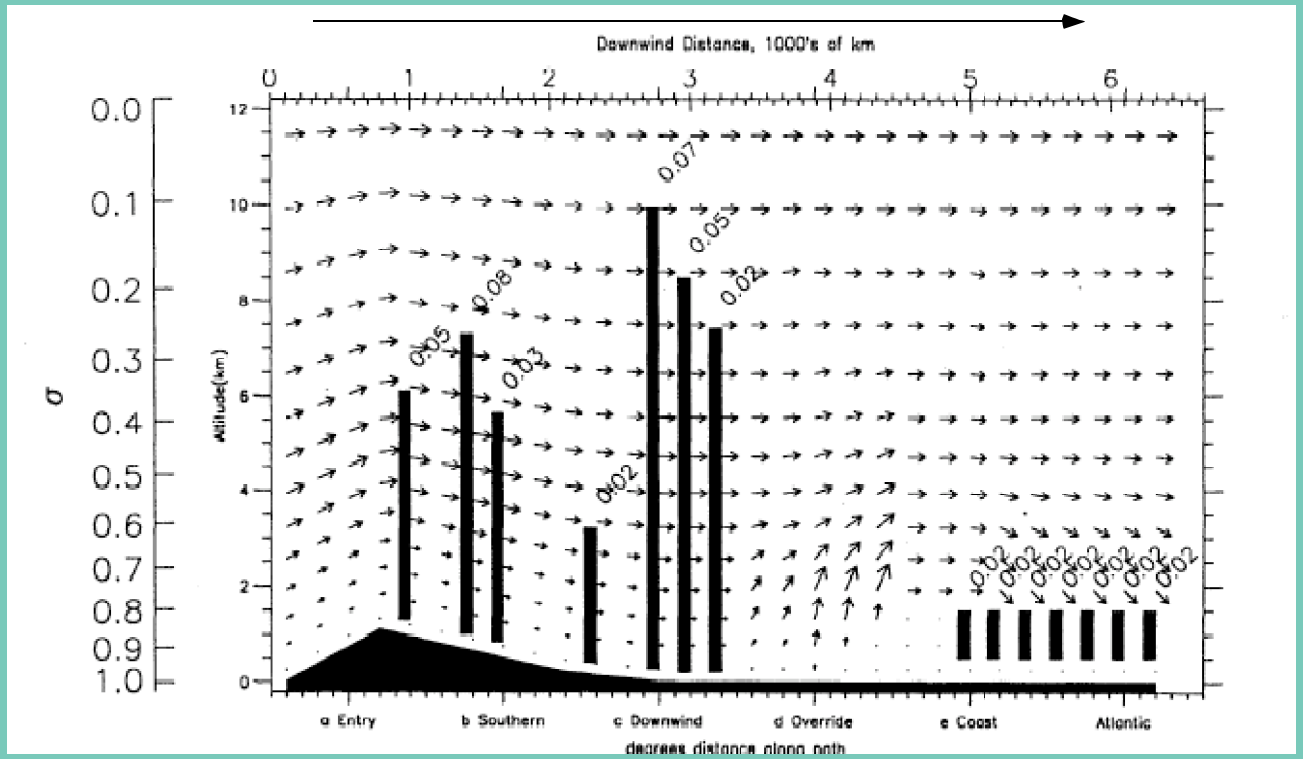
- ***A simplified conceptual model useful to explain vertical mixing and transport***

Chatfield et al., 1996
NASA program 579-24-13-10



- *A simplified conceptual model useful to explain vertical mixing and transport*

Generalized flow for the two-dimensional model of PBL and cloud lofting



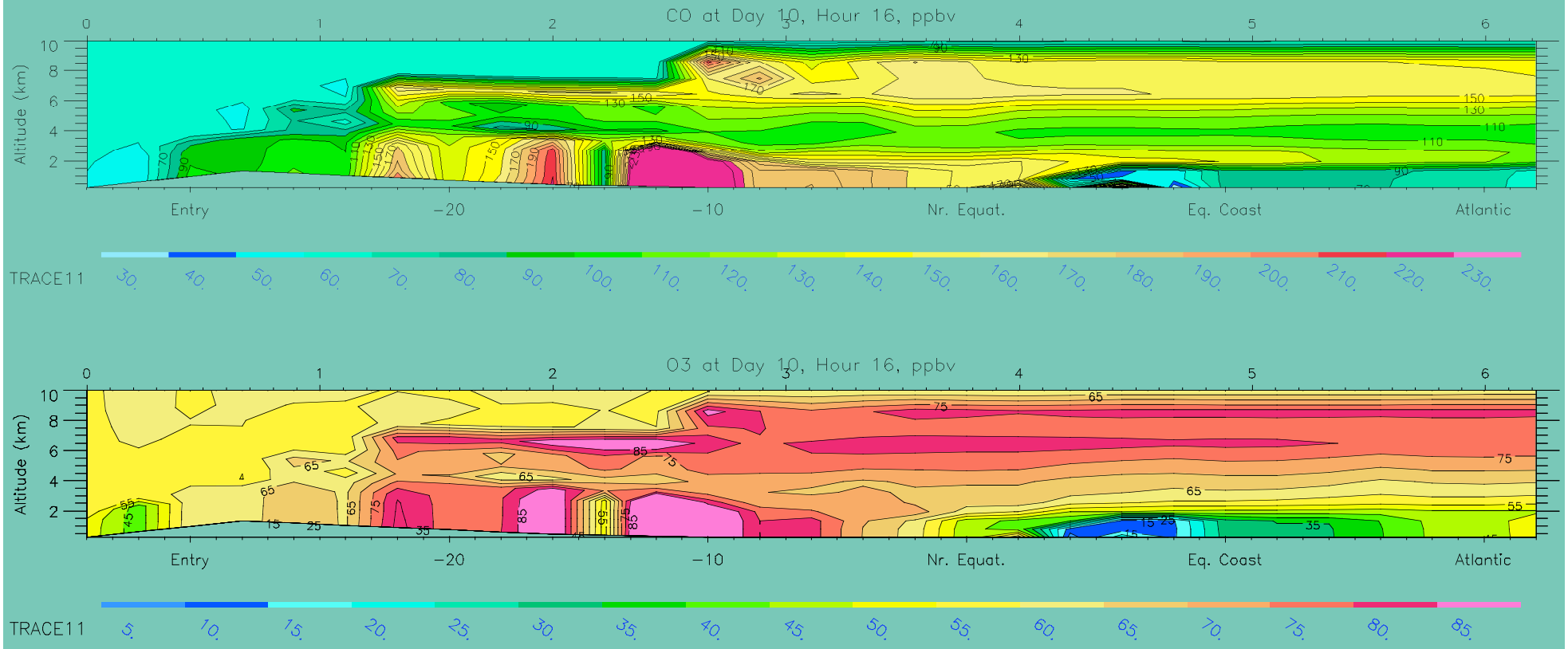
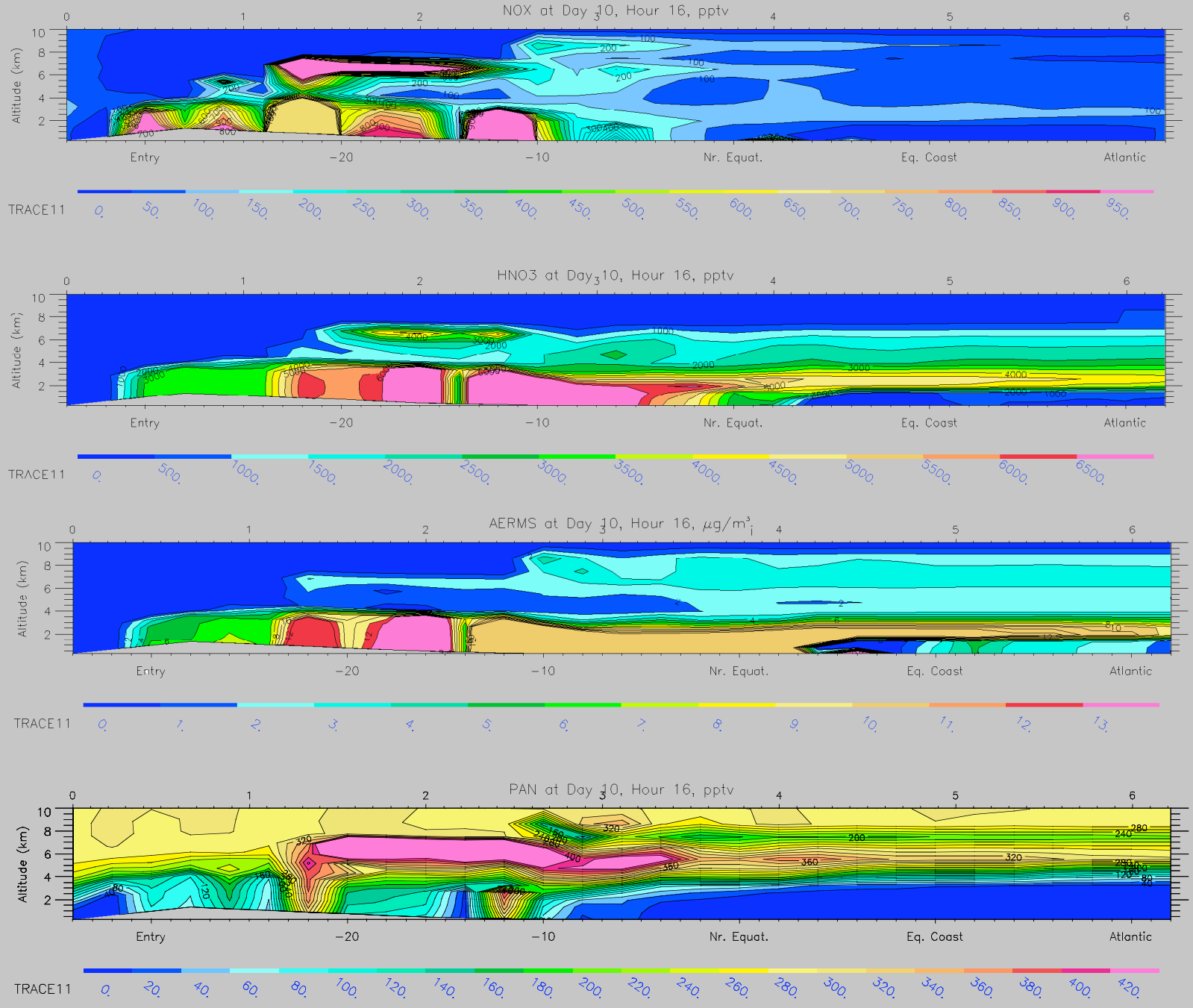

CO at Day 10, Hour 16, ppbv
Altitude (km)
Entry
−20
−10
Nr. Equat.
Eq. Coast
Atlantic
TRACE11
30. 40. 50. 60. 70. 80. 90. 100. 110. 120. 130. 140. 150. 160. 170. 180. 190. 200. 210. 220. 230.
O3 at Day 10, Hour 16, ppbv
Altitude (km)
Entry
−20
−10
Nr. Equat.
Eq. Coast
Atlantic
TRACE11
5. 10. 15. 20. 25. 30. 35. 40. 45. 50. 55. 60. 65. 70. 75. 80. 85.

Figure 7

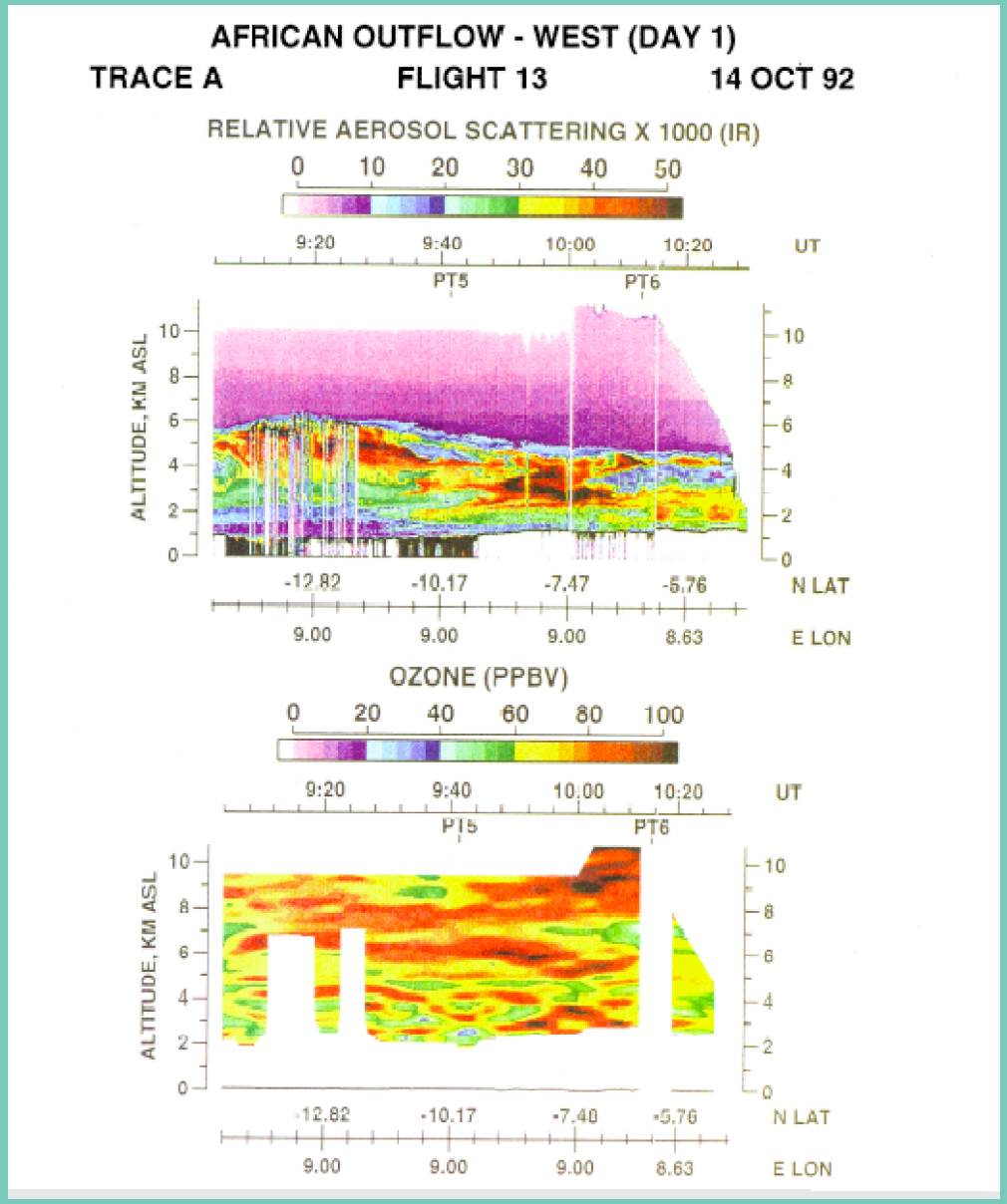

NOX at Day 10, Hour 16, pptv
HNO3 at Day 10, Hour 16, pptv
AERMS at Day 10, Hour 16, μg/m³
PAN at Day 10, Hour 16, pptv
Altitude (km)
Entry
−20
−10
Nr. Equat.
Eq. Coast
Atlantic
TRACE11
0. 50. 100. 150. 200. 250. 300. 350. 400. 450. 500. 550. 600. 650. 700. 750. 800. 850. 900. 950.
TRACE11
0. 500. 1000. 1500. 2000. 2500. 3000. 3500. 4000. 4500. 5000. 5500. 6000. 6500.
TRACE11
0. 1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13.
TRACE11
0. 20. 40. 60. 80. 100. 120. 140. 160. 180. 200. 220. 240. 260. 280. 300. 320. 340. 360. 380. 400. 420.

Ozone and Particles as sensed by DIAL Lidar in SAFARI-92/TRACE-A

a scavenged species

a species whose plume is emphasized in the upper troposphere

Browell lidar, NASA Langley
Chatfield et al., 1996



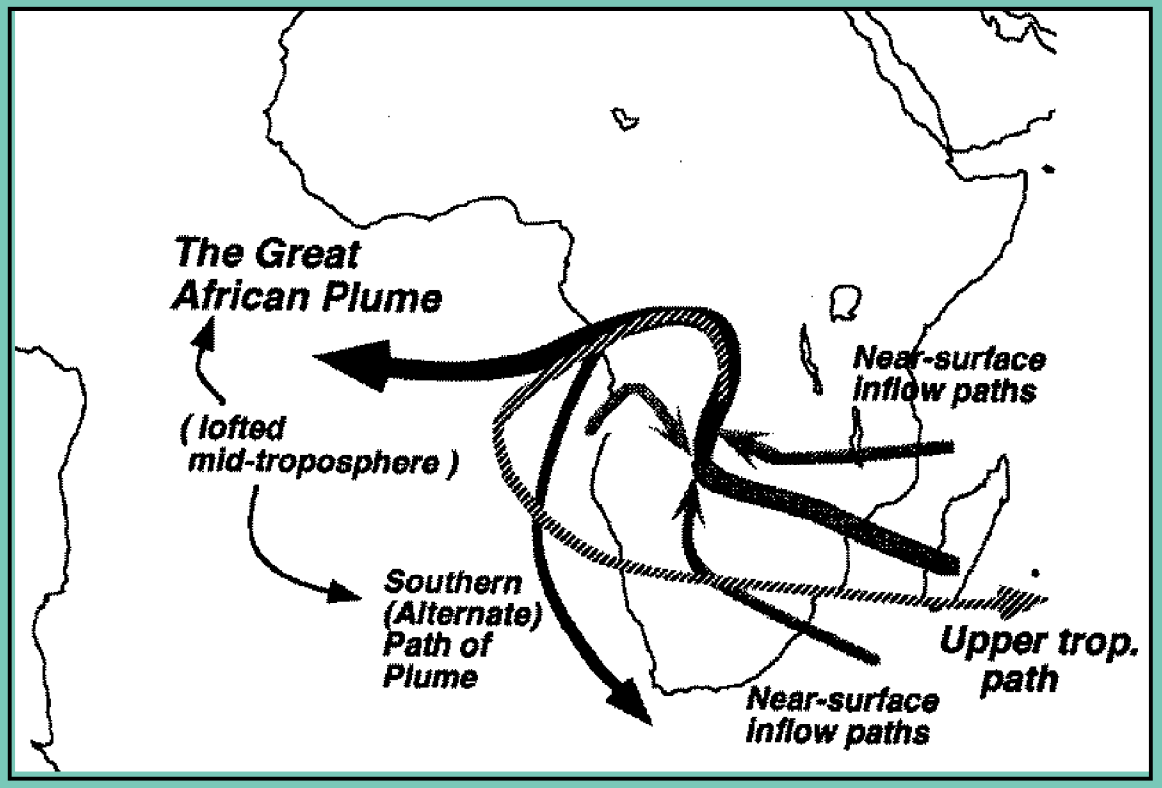
note O3 variability

My Early View of Pathways

- *omitting local S. Africa recirculation*
- *emphasizing redirection of mid-tropospheric plumes*
- *role of S. Atlantic fronts and Southwestern African*

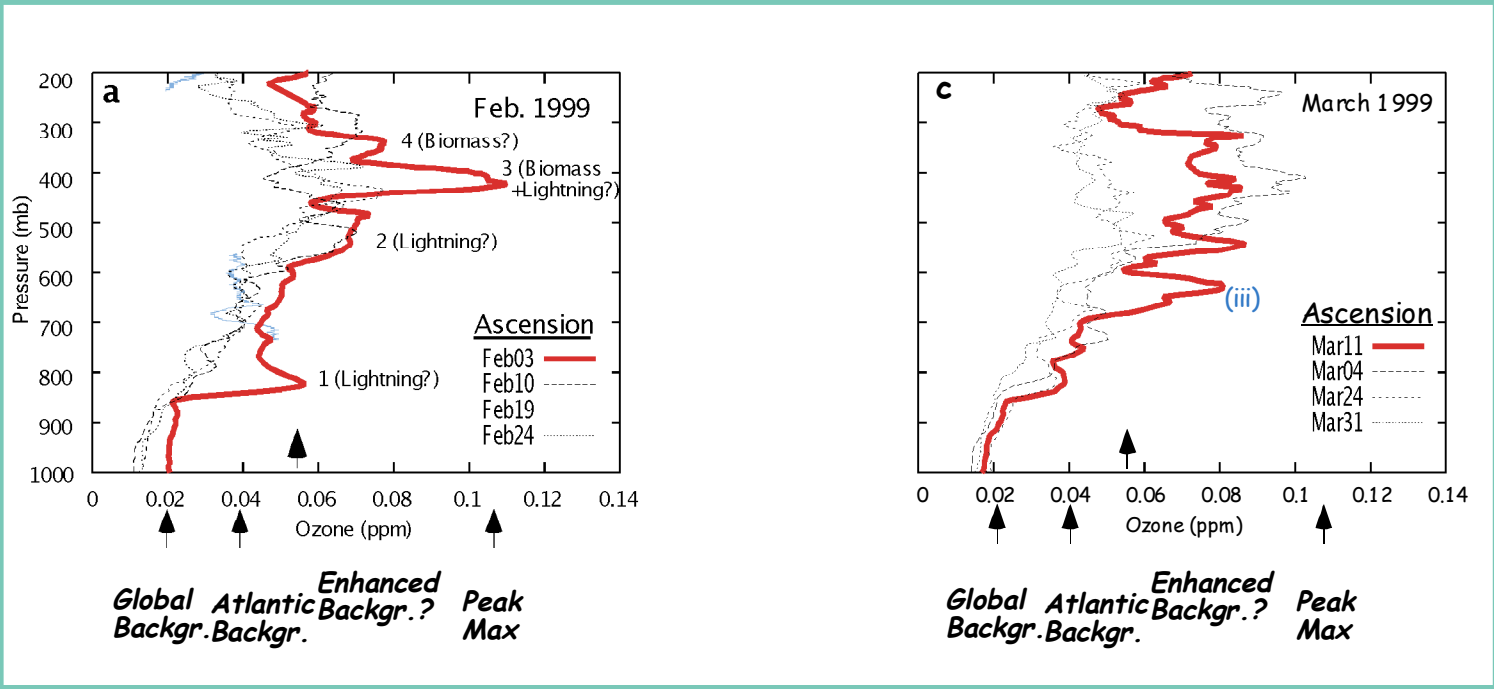
Now "African Equatorial Plume"

- Eq. plumes from Central America
- Indian Ocean Eq. plumes



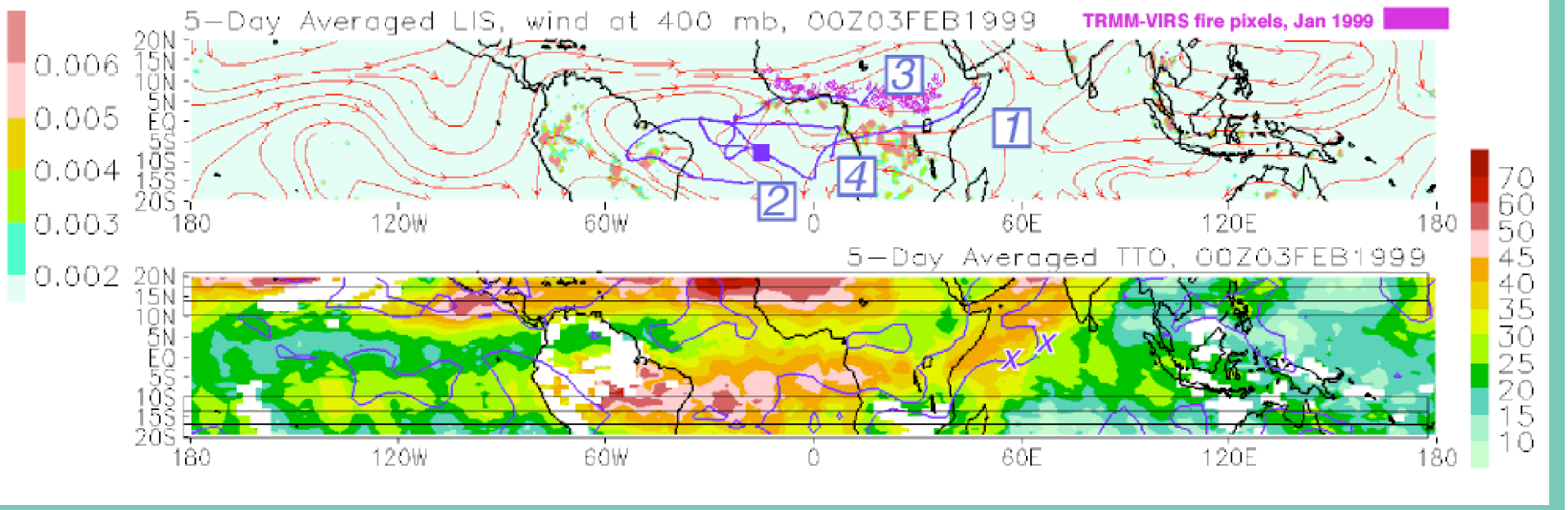
Origin of the Extreme Variability of Tropical ozone Soundings and also ... Variations in General Level

February March Ozone ... after the Southern Burning Season

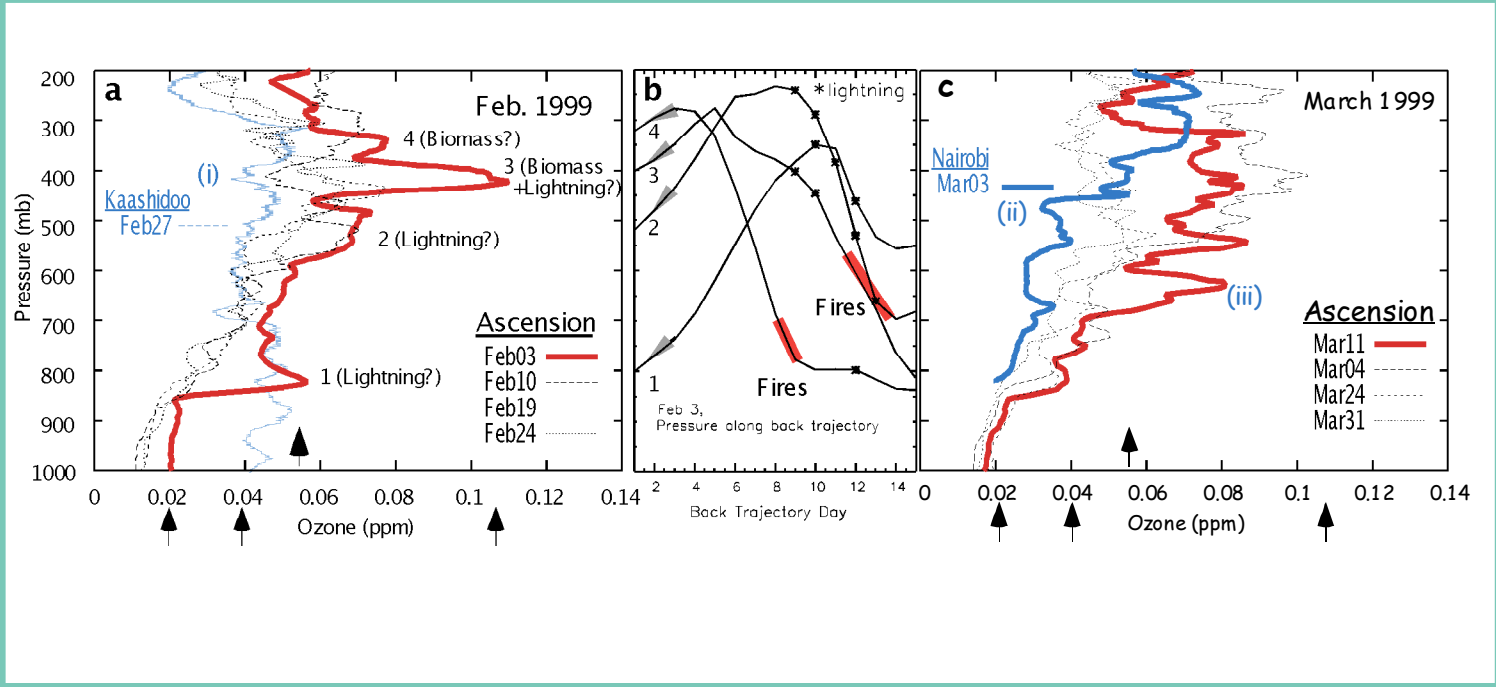


Origins of Ozone Peaks February 3, 1999 Sounding

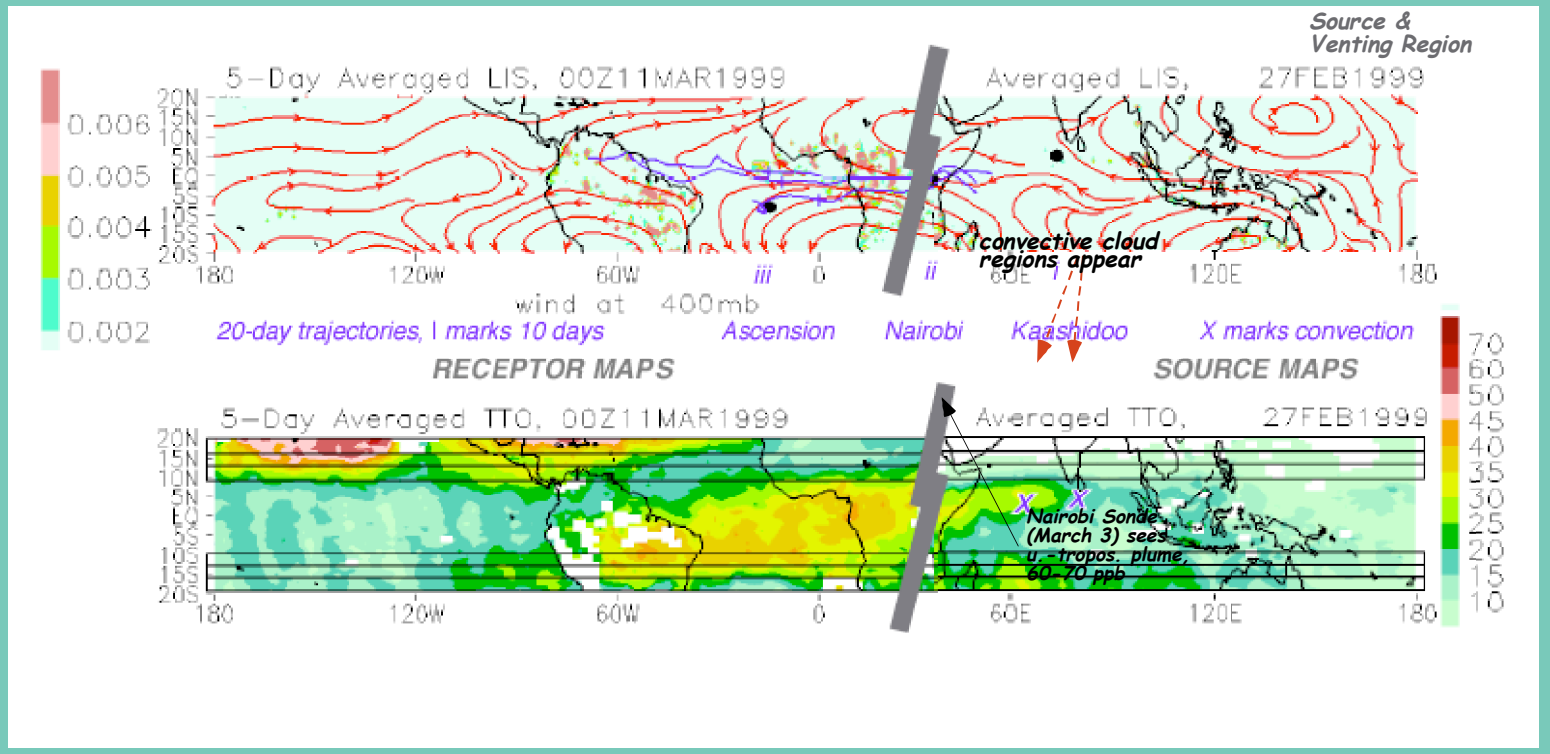
burning, lightning, ... and some background?



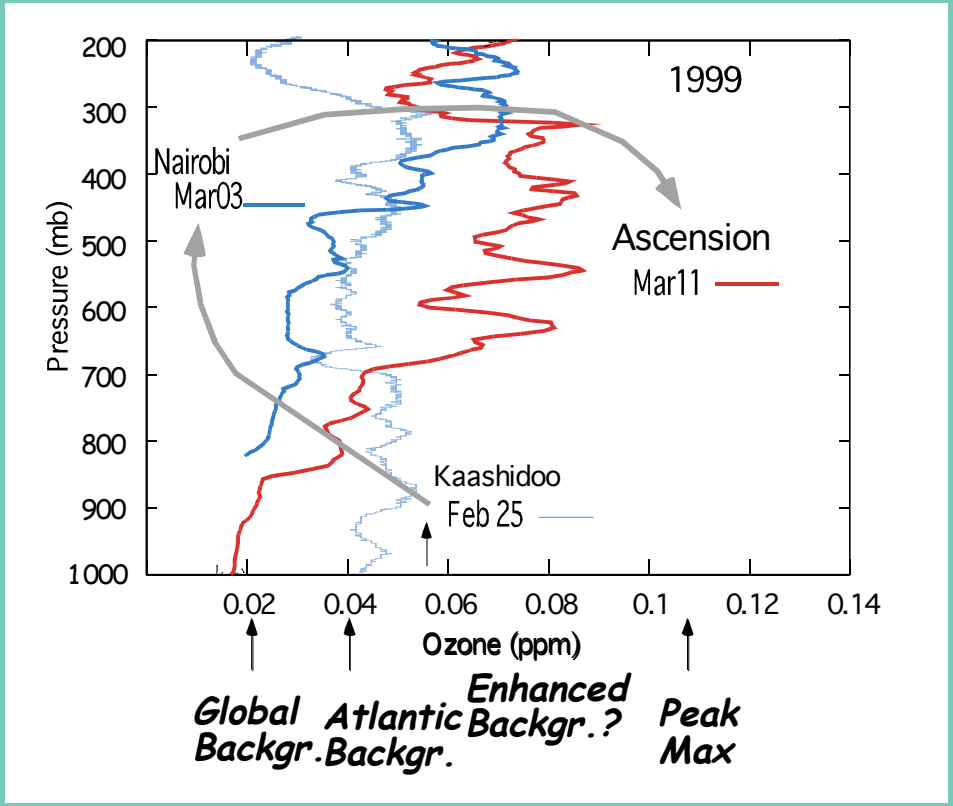
Origins of Ozone Peaks February 3 1999 Sounding: Descent



An analysis of the TTO ozone product along with the Lightning Imaging Sensor product could help explain suggested a W to E transport pattern could explain the highest ozone levels seen in the Ascension Sondes

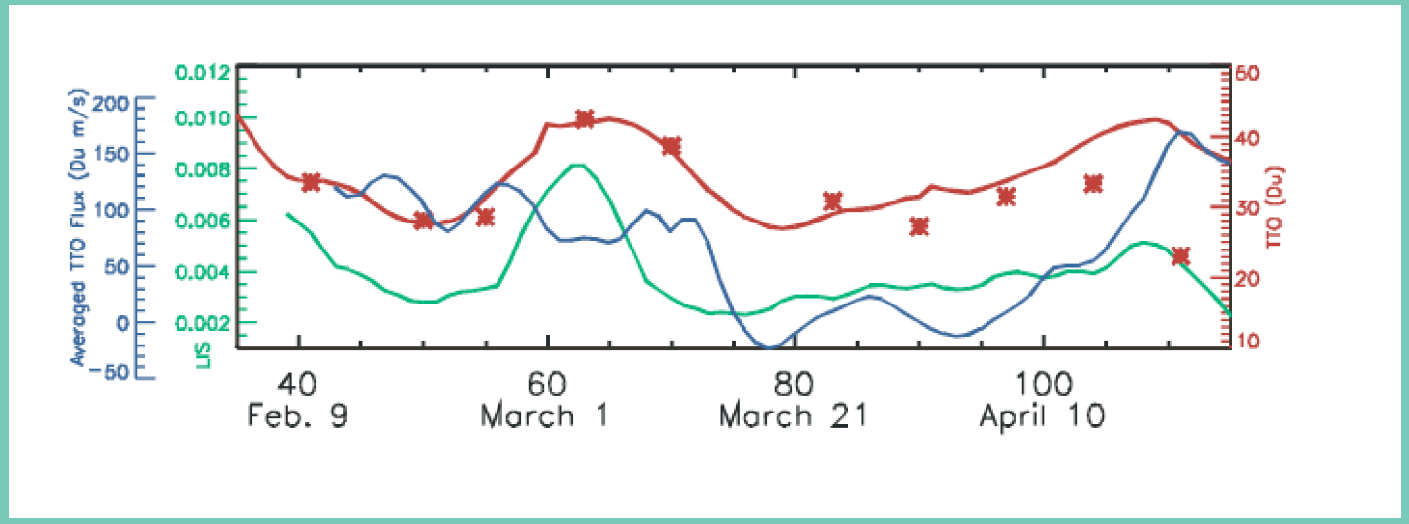


Movie

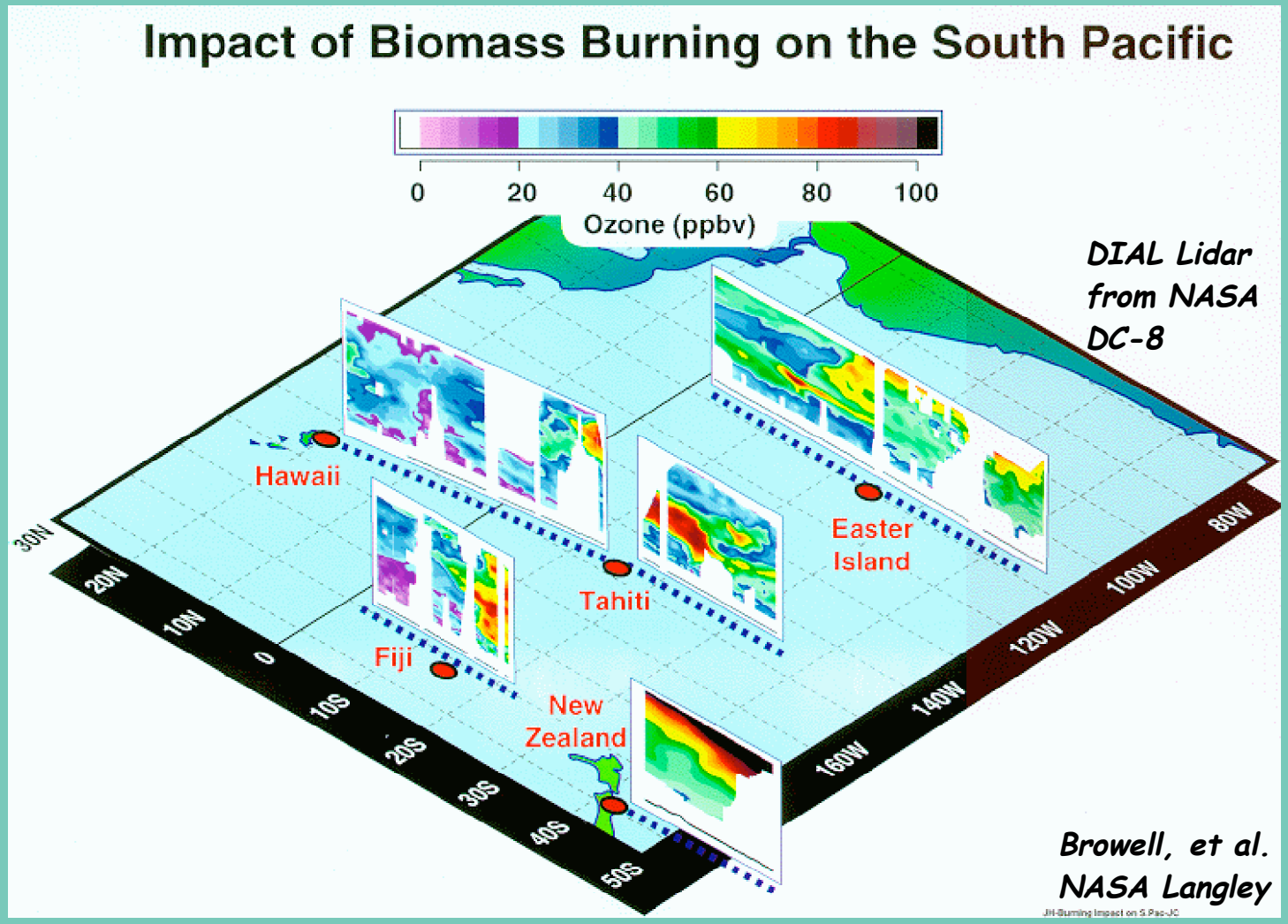


By a great stroke of fortune (or planning), there are 3 ozonesondes which illustrate the transport pattern. The sondes are not exactly along the trajectory, but are linked by common TTO patterns.

Correlation of Ozone at Ascension with
Lightning lagged by 7 days ... lightning from LIS
and
Inflow Ozone from Indian Ocean lagged by 11 days



Unexpected Biomass Burning Plumes at ~10000 km



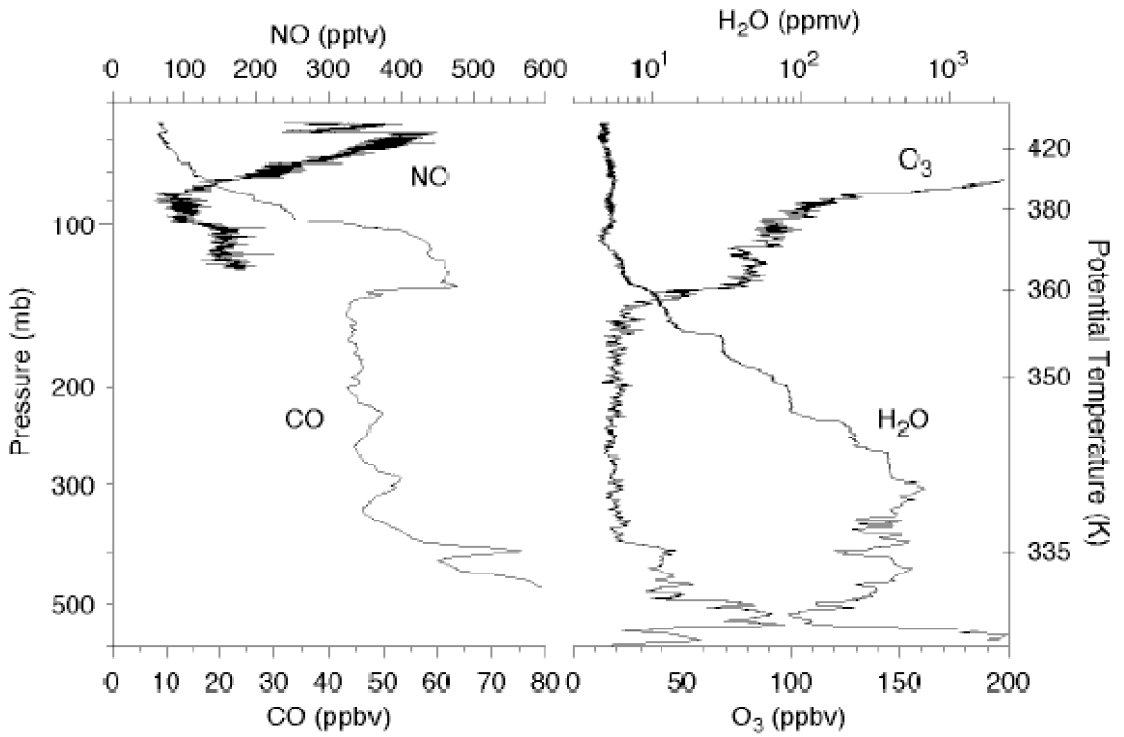
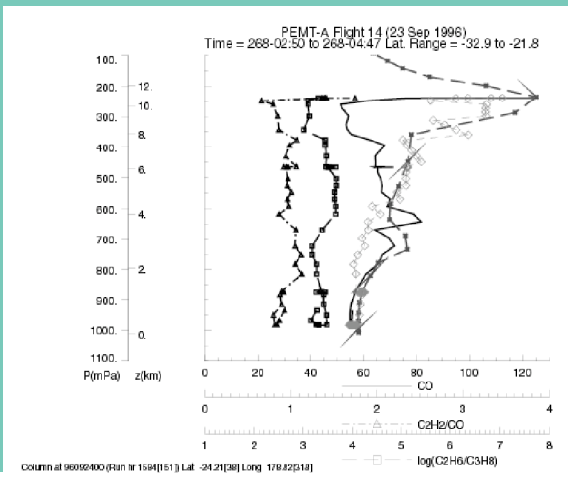
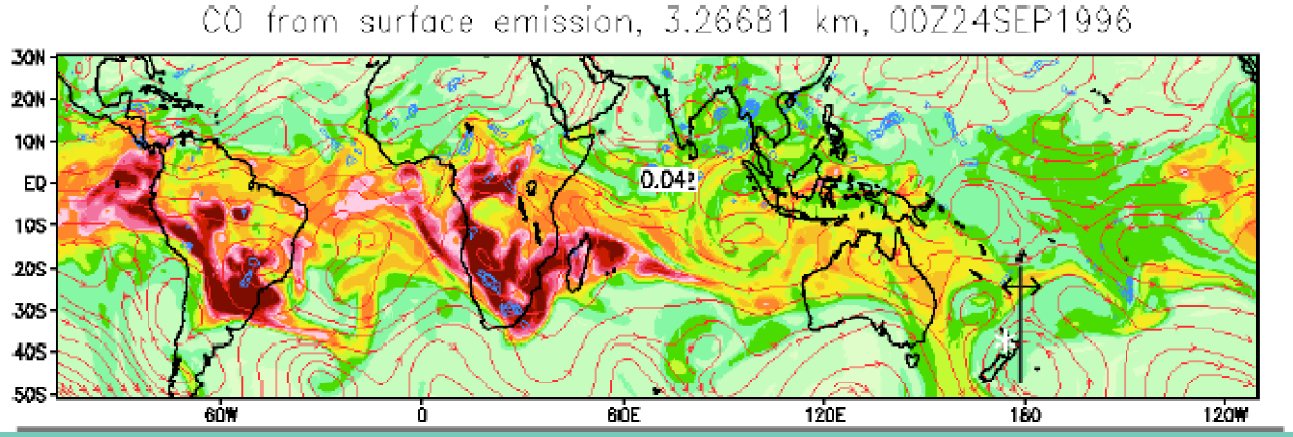


Fig. 3. Analysis of CO, O_3, and H2O for ER-2 profiles observed during ASHOE-MESA [Folkins et al., 1997]. While the O_3 vertical trend is similar to climatology, CO peaks indicate some upper tropospheric O_3 is clearly determined by vertical venting of burning emissions.

A simulation of CO indicated origins of the Southern Pacific plumes in large-scale lofting from Africa and South America.





a

Flight line of NASA DC-8

MM5 simulation of CO tracer;
lower troposphere
showing origin process and situation at DC-8 interception

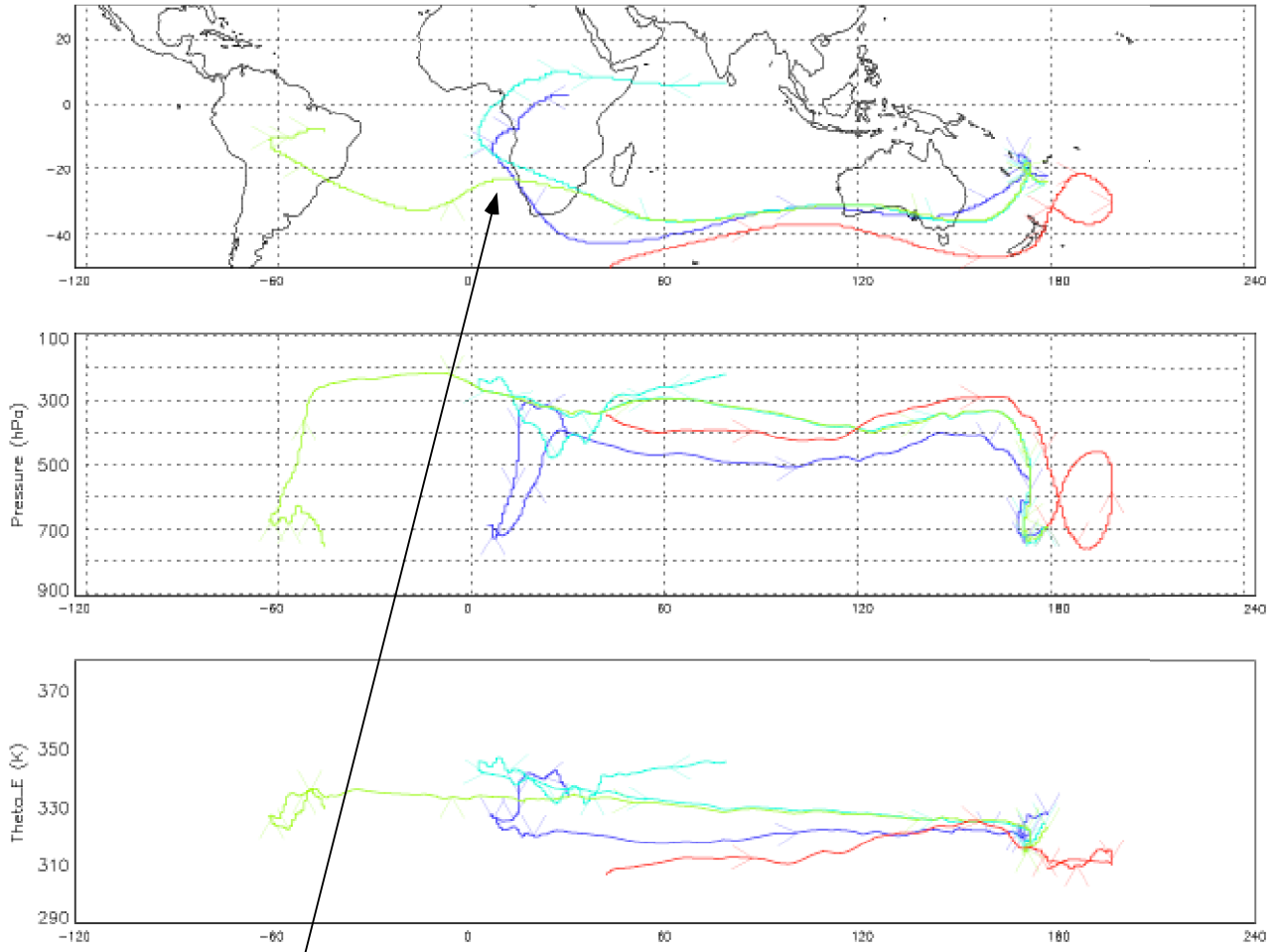
Chatfield et al., 2002

Trajectories using MM5 1-hour winds show typical pathways from S.American and Africa

horizontal

vertical ... pressure

vertical ... potential temperature



This region frequently plays a major directing role

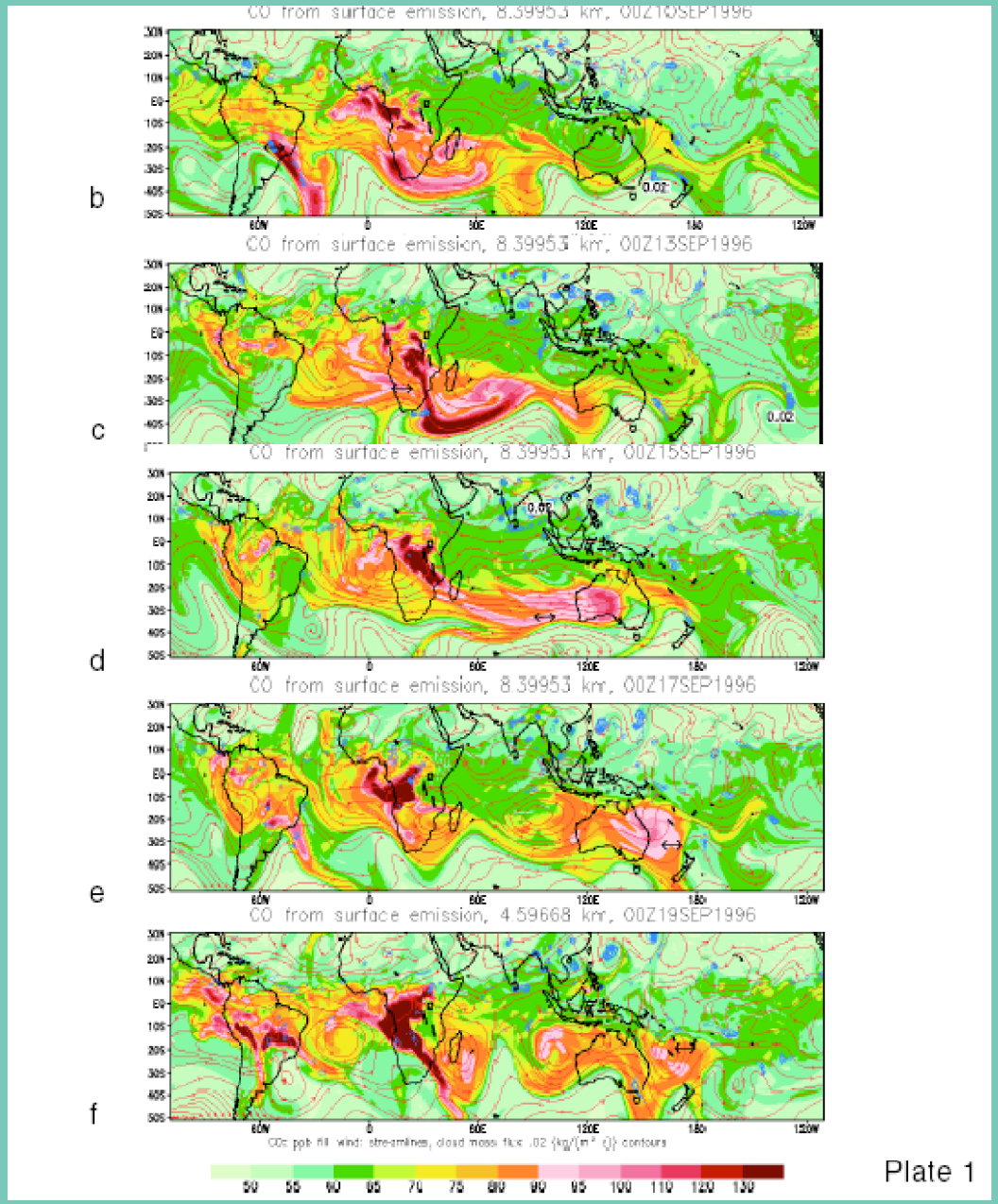


Plate 1

MM5 simulation of CO tracer; lower troposphere

• showing origin process and situation at DC-8 interception

• various altitudes shown corespond to main expression of plume

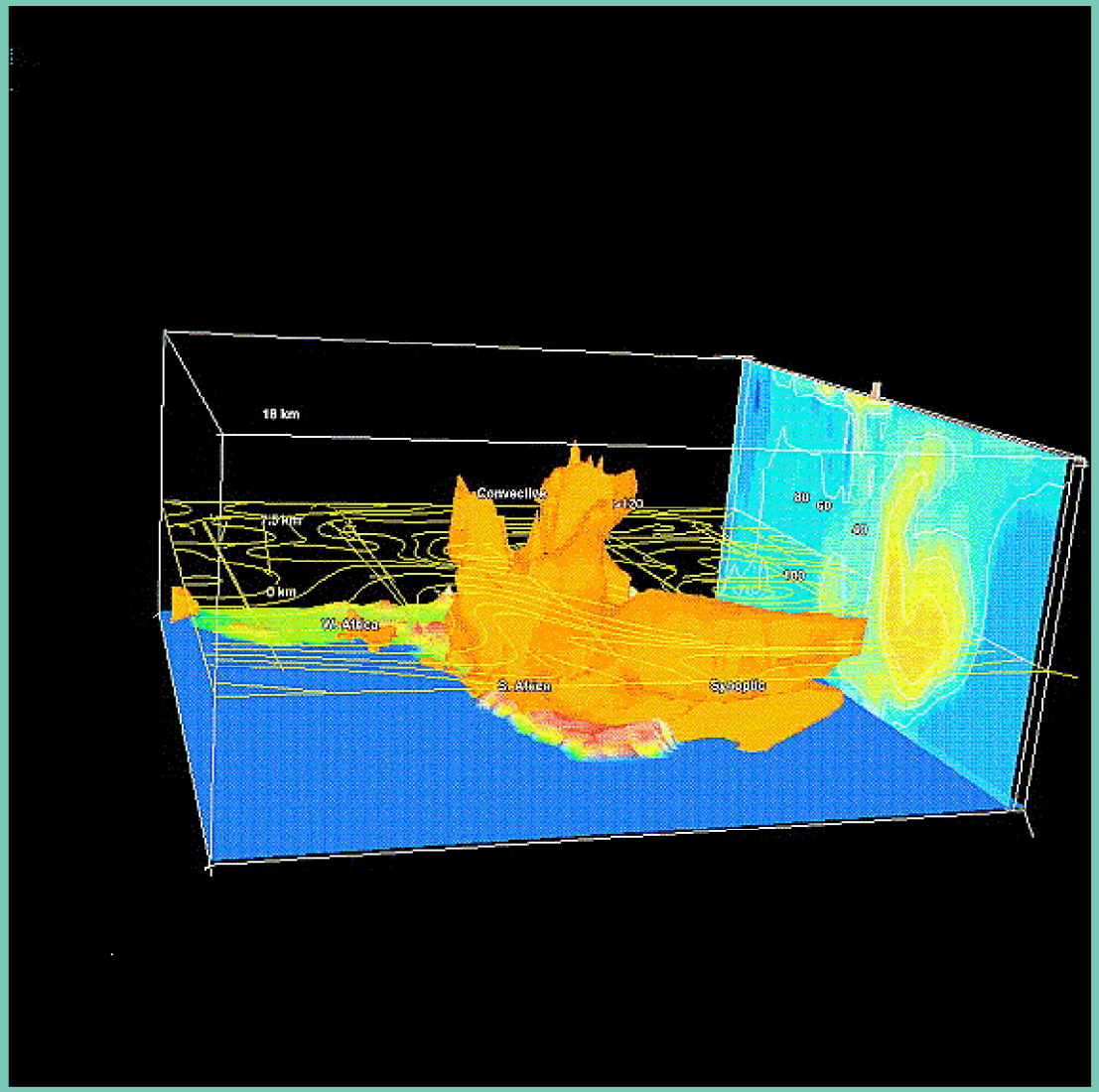
•Hao and Liu inventory-derived estimates were used

• such "high" estimates were absolutely required to match CO near origin ('92) and in the South Pacific ('96)

• Grell convection option for paramaterization of convection in MM5 used; Walcek advection scheme for sharpness, accurate propagation.

(Movie)

Convection and frontal activity can both export pollution effectively

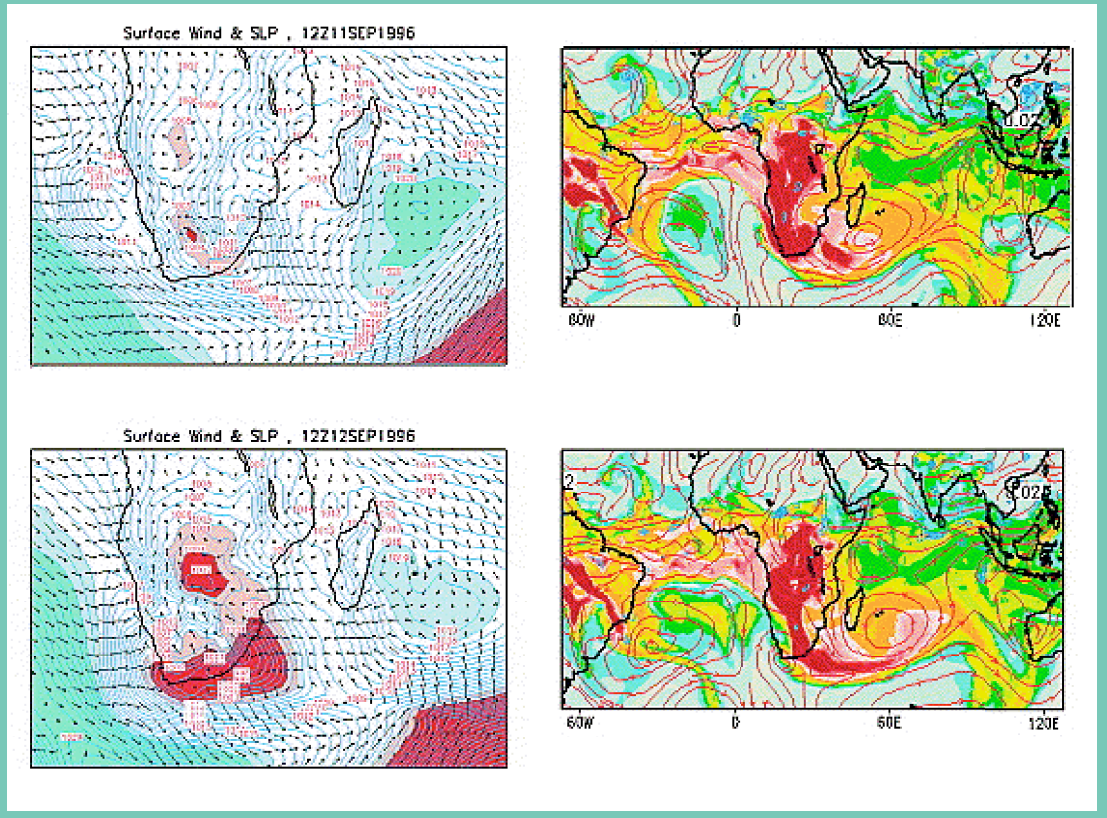


near-equatorial convection

warm frontal activity

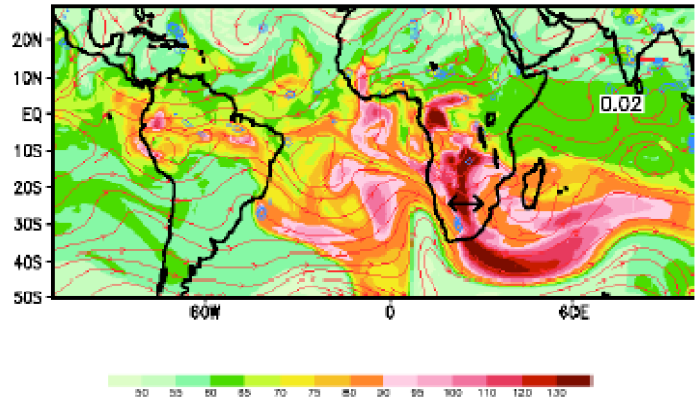
export concentratio

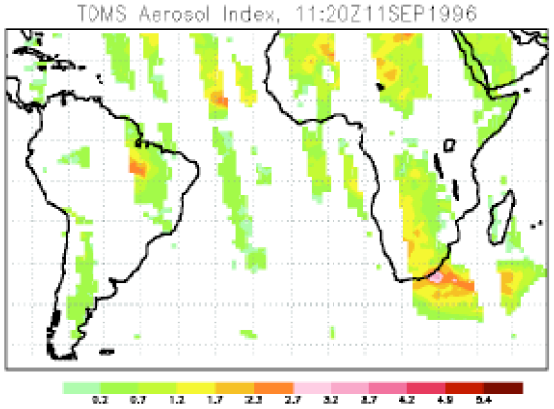
Origins of this megaplume were from a large synoptic front over South Africa and the Westernmost Indian Ocean

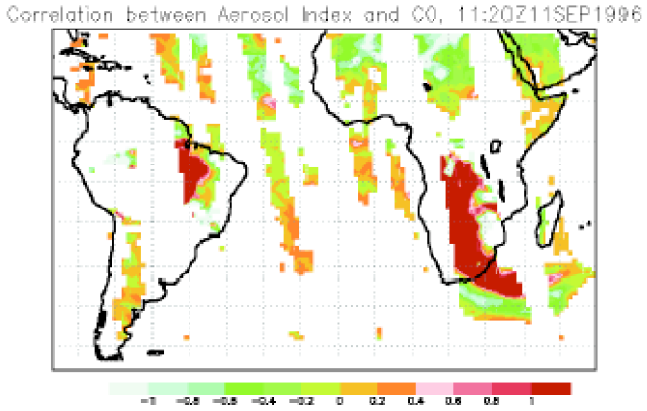


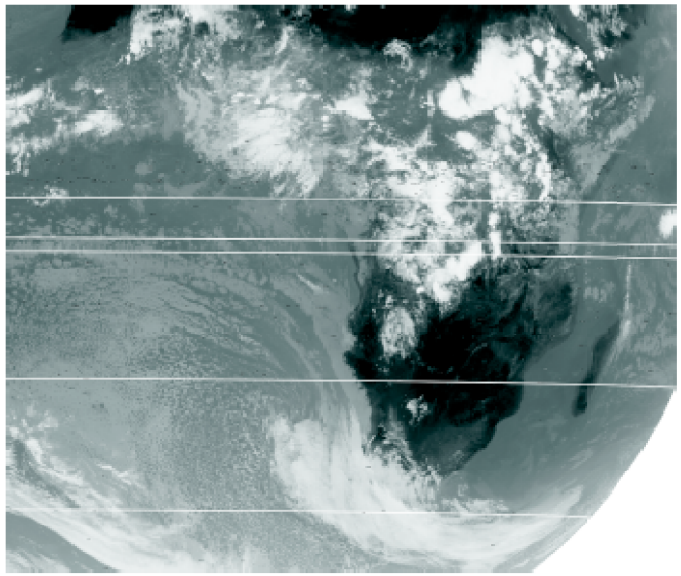
Model, Toms Aerosol Index, and Infrared Clouds

... confirm the great buildup and the role of warm frontal activity over Africa





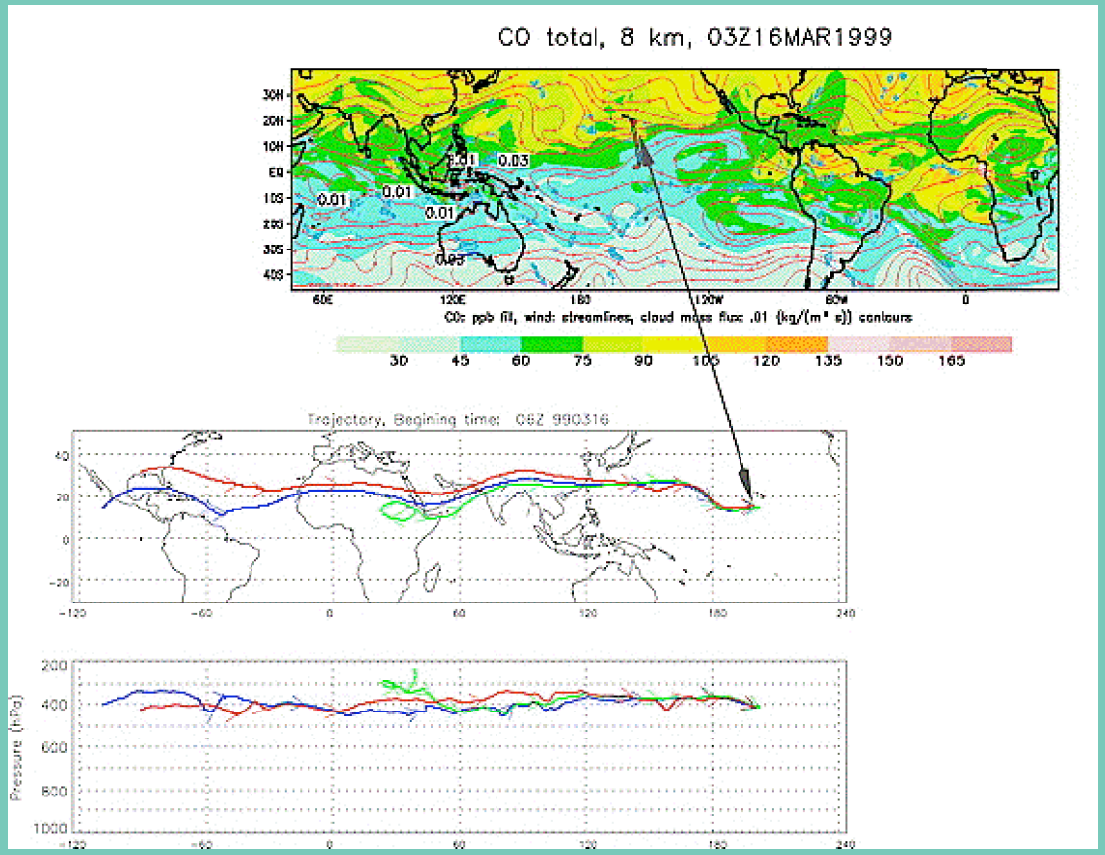




PIC03_Comp_AI_CO_Cld_corr.CNV

Plate 3

Subtropical Global Plumes also occur in the Northern Hemisphere



Movie

Conclusions

- *Equatorial and Southern Africa plays a unique central role in global atmospheric chemistry.*

- *S. America and the Andes provide a major dividing wall, splitting global flows at many levels*
  - *— direct blocking — organization of convection — vigorous fronts, to Equator and Africa*

- *Africa plays a major role as an origin of pollution and lightning emissions*
and also as a "traffic cop" — directing emissions into equatorial or subtropical global plumes

- *Equatorial plumes provide the most visible ozone buildups, ... Jack's Max*

- *Equatorial plumes do create S. Atlantic Ozone also outside of August September October:*
  - *— they can direct ozone from N. African burning season*
  - *— they can supply lightning-produced ozone,*
    - *— frequently immediately following burning season, ... "convection follows the sun"*
  - *— they can channel long-distance ozone from S. Asian pollution*
    - *— perhaps 40% of extra ozone beyond global background is from Indian Ocean*
    - *— other sources of ozone seem to enter the equatorial channel every 20 – 40 days*
    - *— Madden Julian Oscillation ... maybe ... but also African channel formation*

- *Preferential flow to and subsidence south of the Equator means there is no "Atlantic Paradox"*

- *Subtropical Global Plumes take ozone from pollution (and lightning?!) to 10,000 km or more,*
  - *— sometimes back to the Andean wall*
  - *— northern SGP's probably explain pollution towards the south of the Northern Pollution Cap*

- *Stratospheric ozone does affect region ... not addressed*

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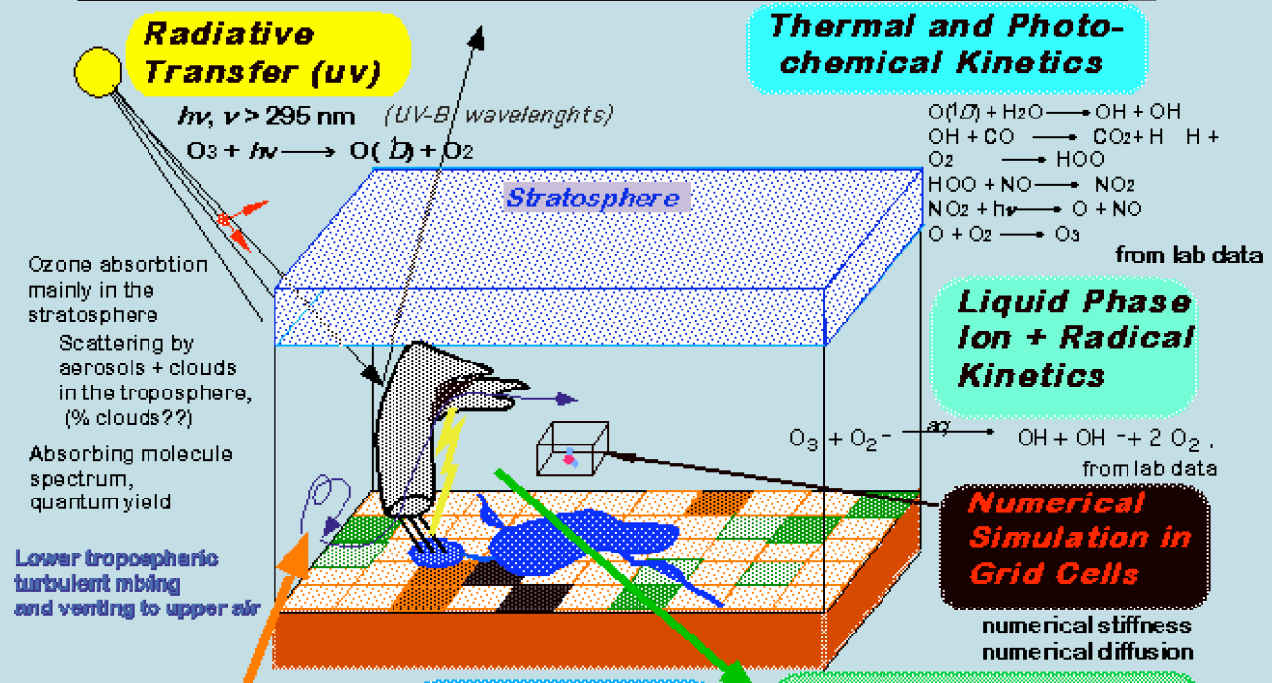
Components of a Photochemical Simulation



Robert Chatfield NASA / Ames R.C. Earth Science